Scope of Work, Fee & Schedule for Rio De Flag Watershed Integrated Hydrologic & Hydraulic Model

From Civil Design & Engineering (CD&E), with DHI

July 2, 2015

In this document, CD&E provides a narrative scope of work and schedule for the City of Flagstaff (CoF) Rio De Flag (RDF) Watershed Integrated Hydrologic & Hydraulic Model. The RDF watershed includes the Upper and Lower RDF watersheds in their entirety.

We propose 4 tasks below, with specific activities in each, followed by a proposed schedule.

Task 1 – Data Preparation/Review/Synthesis

Task 2 – Model Development and Calibration

Task 3 – Post-Fire Runoff Scenario Simulations

Task 4 – Infrastructure Resize and Re-ranking

See Figure 1, below, for a general flow chart. There are iterative feedbacks between Task 3 and Tasks 1 & 2.

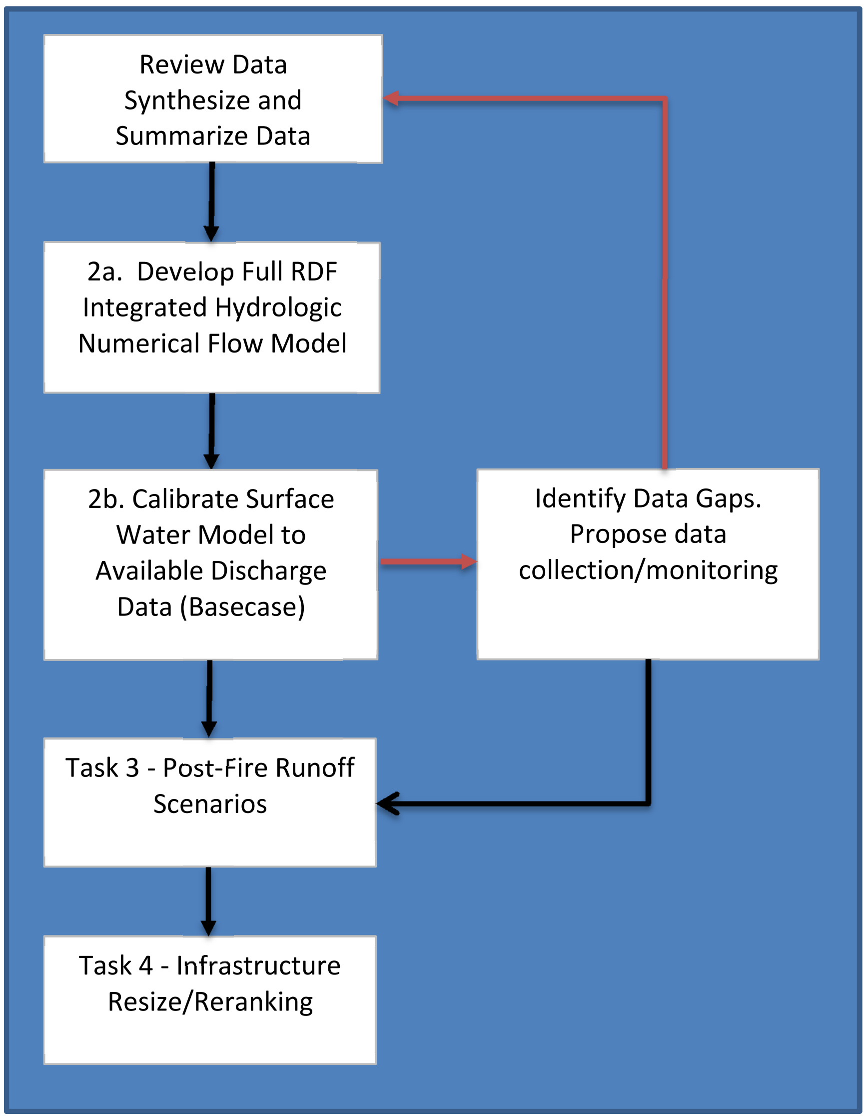

Figure 1. Proposed Project/Modeling Approach

Task 1. Data Preparation/Review/Synthesis

Original Text in RSOQ: *1. Consultant shall coordinate data collection efforts for an integrated hydrologic and hydraulic model for the entire Rio De Flag watershed, terminating at its confluence with Wildcat Canyon. Consultant shall review existing data resources and direct City staff for additional data collection required for adequate model performance. Data resources reviewed and collected may include HEC-2, HEC-RAS, HEC-1, HEC-HMS, selected drainage reports for FEMA regulated floodplains, rainfall and rain gauge data, stream gauge and stream flow data, snow, soils, vegetation, sediment, land use, topography, aerial photos, LIDAR topography, and USGS 7.5 minute quadrangle topography. Sources of data may include the City of Flagstaff, Coconino County, Northern Arizona University, Natural Resources Conservation Service, Arizona Department of Water Resources, United State Geological Survey, National Weather Service, and the National Oceanic and Atmospheric Administration. A summary table shall be prepared that lists and describes the data collected. The table shall include characteristics of the data including, but not limited to, its source, uncertainty, format, and assumptions.*

Proposed Revised Scope for Task 1

Task 1 will require close coordination with City of Flagstaff (COF) staff and informal more-limited coordination with other stakeholders such as Coconino County, Forest Service, USGS, NAU, NRCS, ADWR, and NOAA/NWS. As the integrated hydrologic/hydraulic MIKE SHE/MIKE 11 model ("RDF model") requires substantial input data, we propose summarizing all data provided by the City in our standard Excel 'Data Matrix' template typically used in developing each fully integrated model.

This template facilitates:

- Managing input data (raw and interpreted) in an organized format.
- Data transfers and reporting.
- Identification/tracking of data gaps, evaluation of data quality, and data collection/monitoring to support the modeling effort and reduce uncertainties.

All data in the proposed model can be carefully managed using this template, but it also serves to organize all data for future modeling work to better manage substantial amounts of data, especially as new data replaces old data. All data is arranged into model-relevant categories (see the flow model figure on next page). Data types, subtypes, locations, format, source, interpretations, uncertainty and various notes on quality, quantity, and frequency are included. We will provide the City with the data matrix template at the project start to facilitate data transfer. An added benefit of this approach is promoting the archiving of models of different epoch / age / generation.

Based on current discussions between CD&E and the CoF, we assume/understand the following:

1) CoF has spent considerable time to prepare GIS and other digital datasets that may be used for model development.
2) CoF will spend considerable additional time to finalize datasets from late June to August 1st, 2015, and continuing into August-October as necessary.
3) CoF will provide all key datasets required for input into the models in a readily useable digital format by August 1st, 2015.

Developing a fully integrated, distributed model of the RDF requires careful synthesis, organization of available data. We typically arrange both GIS and tabular data (Excel / Access) in a structured format similar to Figure 2. This greatly facilitates data evaluations, model input, processing, and transfer of the data between parties. GIS information is stored in either geodatabases, or simply shapefiles. With a few modifications, data can typically be input directly into the model.

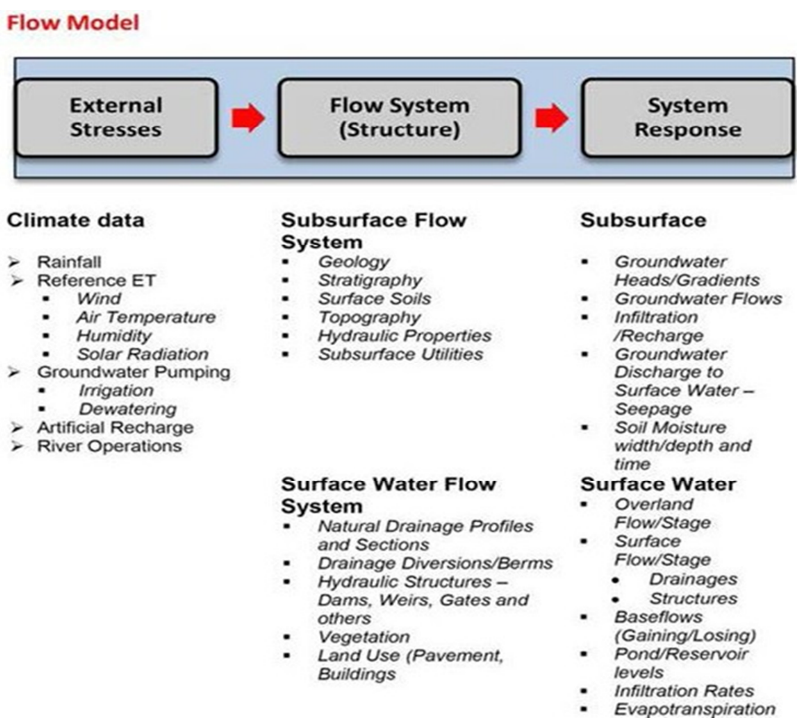

Figure 2. Proposed data organization & types.

Task 1 Proposed Activities/Deliverables:

CD&E will complete the following activities and provide the following deliverables to the CoF upon completion of Task 1.

Activity 1 – Data Template

a) provide an initially incomplete Excel Data Template to the CoF,
b) review all required model inputs for Task 2, Task 3 and Task 4 activities, and
c) jointly help populate the blank fields in the template, as the City develops and provides available data sets, so that the template becomes a continuously maintained database summary throughout this and future projects.

This summary table can help identify initial data gaps and refinement to model development/calibration in Task 2.

Activity 2 – Data Review and Organization

Review, evaluate, assess and directory-organize all useable datasets (consisting of Excel / MS Access, HEC-RAS cross-section, ArcGIS files / geodatabases and other data) to identify those data sets that will be used as part of model development.

Set up a cloud-based project storage utility using Dropbox for use by CD&E and the CoF.

Task 2. Model Development and Calibration

Original Text in RSOQ:

Consultant shall provide to the City of Flagstaff an integrated hydrologic and hydraulic computer model. The model ideally should have the following capabilities and seamlessly integrate the following components of the hydrologic cycle:

- Physically based 2D finite difference hydrologic model capable of modeling temporal and spatial movements of measured or hypothetical storm events with connectivity to NWS NEXRAD data, rain on snow and snowmelt scenarios, and rainfall losses including infiltration,
- Storm sewer collection systems
- Hydraulic modeling of flood conveyances (including hydraulic structures) acceptable for floodplain determinations for FEMA
- Physically based 3D finite difference groundwater model that includes pumping and irrigation effects, water quality and contaminant transport capabilities.

The City of Flagstaff intends to collaborate with other agencies such as the USFS, USGS, NAU and Coconino County to access the code and City GIS resources via remote web applications. The City of Flagstaff anticipates hosting the computer model on its own servers, but may entertain the possibility of cloud hosted software and computing if security issues and logistics can be appropriately addressed. After the base model has been created, this will allow these agencies to run model scenarios and perform various research efforts that can serve to continually improve the model over time. Consultant shall have the capabilities of modifying the computer code to customize the model outputs and input interface for different needs from different departments of the City, and for customizing remote, web-based interface for collaborating agencies to access model input, output, and hypothetical scenarios. Consultant shall input data collected during Part 1 of Task 1 into the model. Consultant shall calibrate the model to available observation data and verify the model with other qualitative methods which may include USGS regional watershed response equations, collected data of fluvial geomorphology data, and other separate and independent computer models prepared by others. Consultant shall conduct model simulations to help focus future data collection to validate model parameters that reduce uncertainty in the model. Consultant shall provide training to City staff for operating, maintaining and calibrating the computer model. Consultant shall advise City staff on using the computer model to simulate highly heterogeneous flood event scenarios including rain on snow, burned watershed and specific thunderstorm super-cell storm event scenarios.

Deliverable: Integrated Hydrologic and Hydraulic Computer Model for the Rio de Flag watershed with capabilities of allowing remote web-based access and interface.

Proposed Revised Scope for Task 2

Proposed Code

We propose using DHI's powerful, fully-integrated, physically- based, distributed-parameter hydrologic/hydraulic code MIKE SHE / MIKE11 that simulates all relevant COF requested processes (see Figure 3 below).

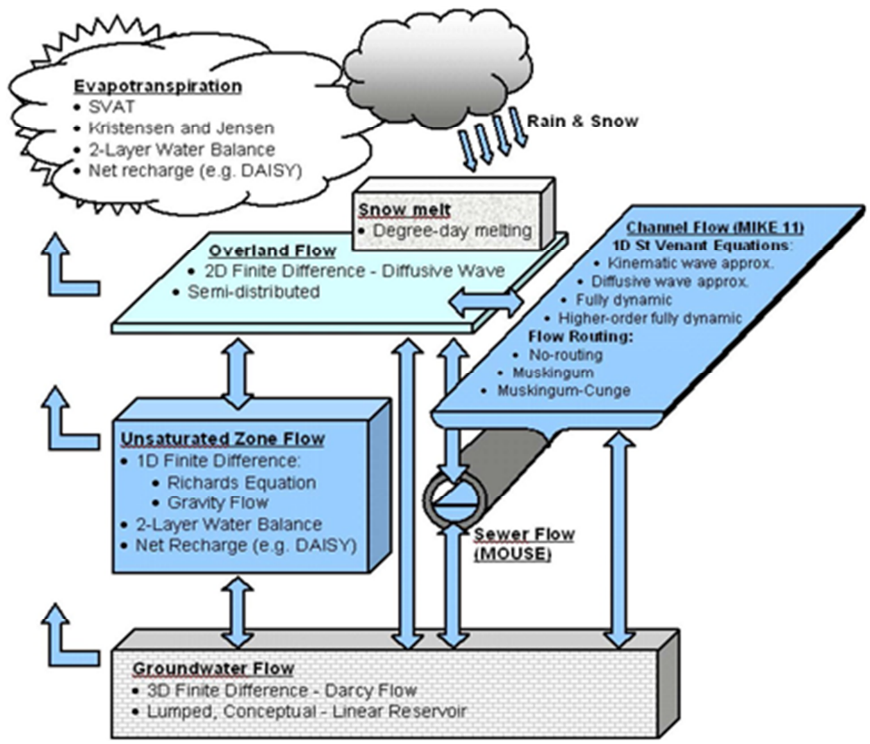

Figure 3. MIKE SHE/MIKE 11 Code Process Options and Links

KEY PROCESSES SIMULATED:

1. 1D fully-hydrodynamic channelized streamflow (or pipe), with a wide array of hydraulic structures and easily-scripted complex operations using FEMA approved MIKE 11 code
2. 2D Diffusive-Wave (St. Venant Equations) overland flow (DEM- based).
3. Fully 3-D Groundwater Flow capabilities similar to Modflow
4. 1D Unsaturated Zone Flow
5. Snowmelt (Modified Degree-Day) with spatially/temporally variable inputs, sublimation, dry or wet snow dynamics and rain-on-snow capabilities
6. Evapotranspiration, which calculates various losses, including pond evaporation, soil evaporation and plant transpiration and based on spatial/temporal distributed crops, soils and variable soil moisture.
7. Pond Evaporation Complex irrigation capabilities where different sources (river, wells, external) are specified in numerous options to fields.

Activity 1 – Model Development

We will develop an integrated regional model of the entire RDF watershed, which consists of the Upper and Lower RDF, Doney Park & Sinclair Wash watersheds – see Exhibit 1, using a coarser grid discretization (~ 100 meters to start). Simulation results from the regional model will be used to define an external time-varying surface water (overland and channelized water) inflow boundary condition to a localized, high-resolution model (see Exhibit 2). The refined grid in this local-model area will better resolve overland flow contributions into the channelized 1-dimensional MIKE11 drainage network in a critical area of the City, where key structures are currently known to be undersized, and which will form the focus area for Tasks 3 and 4. The exact configuration of this high-resolution grid will be refined during the calibration process as model performance and system dynamics become better understood. The MIKE 11 hydraulic stream network developed for the regional model will be used in the local high-resolution RDF model, as the coupling method is automated and all structures will be active in both models. However simulated output from the regional-scale model MIKE11 channels will be specified as input boundary conditions on all upstream 1-D branches crossing the local model boundary.

As part of the original RSoQ, the City anticipated financial and other participation on the part of Coconino County in the integrated hydrological and hydraulic model development. The City has since learned that the County has already paid consultants to develop, house, and run 2D flow models for the mountain and alluvial fan settings on the East flank of the San Francisco Peaks (Shultz Fire burn areas and downstream neighborhoods). Having paid heavily for and apparently being satisfied with those models, we understand that the County will not participate in the current endeavor. However, we assume that the CoF will obtain from the County current 2D flow model input & output, and related information (reports, presentations, etc.), for use on this project to help with parameterization of post-fire conditions (in Tasks 3 & 4, below). We are not insisting that the County provide us with the actual model if they are not comfortable with releasing it to the CoF for use on this project, but it will be very useful to work from the same dataset/assumptions for consistency.

Thus, it makes sense that this task focus on regional-scale (~100 m, or finer if possible) catchment model development for the Upper and Lower RDF, Doney Park and Sinclair Wash catchments, and on those sub-catchments, such as Clay & Spruce Avenues (and not on the Doney Park sub-catchments) that will need to be developed to capture flow dynamics associated with smaller-scale features in these areas, in order to fulfil the emphasis of this project on 1D flood forecasting on the upper Rio de Flag.

We understand that this project doesn't require that we develop and calibrate a fully integrated model, in which the surface flow system is coupled with the groundwater flow system. If time permits, we will, at our option, within the spatial extent of the CoF MIKE SHE/MIKE 11 model, add in the CoF's recent AMEC-modified NARGFM groundwater MODFLOW-based model input into the MIKE SHE model. This would include all production/monitoring wells and multiple aquifers/aquitards, though groundwater recharge would be determined based on actual infiltration and evapotranspiration dynamics calculated by long- term climate inputs. This would demonstrate to the COF the model's ability to address fully-coupled problems, for example where groundwater flow and water quality problems relate to surface waters. CD&E can demonstrate how the setup is done, and provide results from preliminary modeling (not calibration) using the fully coupled model (with groundwater). A groundwater element would be advantageous to securing the involvement of stakeholders such as NAU and the USGS.

The 2D MIKE SHE overland flow coupled to the MIKE 11 1D hydrodynamic channel flow and 1D infiltration/evapotranspiration regional-scale model would be calibrated first to reduce computational overhead. Though correctly modeling the entire storm sewer collection system is beyond the scope of this budget, assuming their flows are comparatively small relative to main RDF pre- and post-fire discharges, we could reasonably account for their flows by treating them as channels in MIKE 11 if needed/requested by COF, for example in the localized, high-resolution RDF model (Exhibit 2). Though not included in this effort, DHI's MIKE URBAN software could always be purchased and used in a later phase of work to link MIKE SHE/ MIKE 11 with the explicitly defined subsurface stormwater drainage pipe network to evaluate local-scale dynamics in detail, if of interest to the COF at a later date.

Activity 2 – Model Calibration

Key parameters within the integrated 2-D overland flow model coupled to the 1-D MIKE 11 channelized flow network and associated structures and to the 1-D unsaturated zone/evapotranspiration module will be calibrated to stream gage stage and/or discharge data made available to the CD&E team throughout the model domain. The ability to calibrate the regional-scale model will strongly depend on the locations, frequency and quality of available discharge (and/or stage) data, and complexity and influence of flow within sub-catchments.

Data Gaps - Typically during model calibration we assess model performance against available stream gage data; where performance is poor, we can identify what/where additional data can be collected to improve better model calibration.

In coordination with COF, we will complete a comparison at a limited number of locations of MIKE SHE/MIKE 11 model results and results other available surface water hydraulic models (i.e., HEC models) where appropriate and available. This comparison will not get into adjusting MIKE SHE/MIKE 11 model parameters to bring results into conformance with earlier / other hydraulic model results.

Activity 3 - Model Training

CD&E proposes Schlinger and Prucha be available during Task 2 to work closely with the COF. Schlinger and Prucha will demonstrate how the model is developed, how high resolution sub-catchment models (telescoped) are developed and use regional model output as boundary conditions, how these models are calibrated, and how to develop and run scenarios and evaluate their output. We believe this would make COF modelers proficient and enthusiastic at further model development and use, especially during possible troubleshooting situations. This training provides ample understanding of modeling assumptions.

Task 2 Deliverables

Model input and output, recommendations on additional data collection/monitoring to improve model calibration and scenario predictions, and a presentation to the COF and interested stakeholders.

Task 3. Post-Fire Runoff Scenario Simulations

Original Text in RSOQ:

Assess potential for and provide recommendations for mitigation(s) related to wildfire and post fire flooding. Task includes mapping of hazards and consideration of the approved 4 Forest Restoration Initiative (4FRI) for forest treatment and the recently approved City Bond for forest health (FH). Hydrologic modeling to determine discharges affecting the City will be prepared based on the most probable scenarios.

Deliverables: A map showing all areas of the watershed that are proposed for forest treatment and identification of critical forest treatment that remains. Utilizing available data from the Schultz Burn and other resources, develop likely fire scenarios post forest treatment by 4FRI and FH. Based on the most likely fire scenario, calculate post fire flood discharges. Provide a pre- and post-fire inundation map of affected areas of the County and City.

Proposed Revised Scope for Task 3

Development & Evaluation of Planned 4FRI Forested Watershed Treatments.

See: http://www.4fri.org/documents.html

Our team will work closely with the City (and stakeholders) to:

1. Identify proposed and remaining 4FRI and FH treatments;
2. Define specific fire scenarios to evaluate in this task. CD&E proposes up to ten scenarios will be developed, run and evaluated in detail for this task.

For each fire scenario, specific changes in model inputs (i.e., soils, vegetation, topography, etc.) will need to be carefully determined in coordination with the City and stakeholders.

We propose the following steps for Task 3:

1. Simulate a combination of post-fire plus climate scenarios (late summer local convective/intense fires, spring freshet, winter storms, etc.) plus uncertain fire input parameters (i.e. soils/ vegetation from Schultz Burn) to account for input uncertainty.
2. Develop a range (up to 10) of simulated discharge responses and flood inundations at specific areas of interest, indicating which combination of conditions lead to the worst case and mid- level impacts. The City needs to know what combinations lead to the worst case scenario, and then develop mitigation plans accordingly. The worst case scenarios could point to high uncertainty related to input parameters, highlighting data gaps.
3. Work closely with the City (and stakeholders) to develop a set of possible mitigation strategies to reduce overall risks associated with strategy for scenarios.
4. Simulate the selected mitigation for a conservative (i.e., worst-case) and mid-level scenario combination (post-fire and climate) to demonstrate overall utility of the model used in conjunction with mitigation plans.

Simulation of single events will be fast. A key objective for the CD&E team will be to work closely with CoF throughout this process to ensure appropriate development of model inputs and evaluation of model outputs.

Task 3 Deliverables

Model scenario details, and all model input and output files (up to 10 simulations). A map showing all areas of the watershed proposed for forest treatment and identification of critical forest treatment that remains. Provide a pre- and post-fire inundation map of affected areas of the County and City for the conservative (worst-case) scenario and a mid-level impact scenario. Provide a post-mitigation inundation map for the worst-case scenario.

Task 4. Infrastructure Resize Scenarios / Infrastructure Re-ranking

Original Text in RSOQ:

Consultant shall determine specific locations where infrastructure is significantly undersized with respect to 100-year flows and the post fire discharges. Additionally, consideration of the effects of climate change for the region, such as more intense rainfall events shall also be considered in selection of undersized infrastructure. Up to 20 locations will be identified in the City and County. Consultant shall prioritize possible infrastructure improvements utilizing the City adopted ranking criteria, and provide preliminary cost estimates for the improvements.

Deliverables: A prioritized list of locations in the City of Flagstaff stormwater infrastructure network that are significantly undersized, and provide preliminary cost estimates for their correction and priority rankings according to the adopted City ranking criteria.

Proposed Revised Scope for Task 4

We propose an iterative approach to Task 4. Using FEMA design storm events, and existing structures, we will systematically enlarge individual structures, one at a time, beginning at the upstream end of reaches of interest, and evaluate effects and prioritize remaining structural adjustments to mitigate underperformance. CD&E assumes up to 20 single-event simulations will be run for this Task. Close coordination and ongoing training will enable CoF to develop in-house capability and knowledge of how to perform these types of simulations.

We will address the following question: "Does fixing 1 major structure problem simply create an even bigger problem elsewhere, or must a specific set of structures be changed to really reduce overall risks to the CoF?" Results may indicate that significant risk reduction can only be achieved by fixing multiple structures; the challenge would be finding the right combination through iterative modeling (i.e., fixing different sets). We believe iteratively simulating specific sets will provide considerable insight into which combination of structures should be addressed along with city criteria and costs.

It is possible that, where we find additional underperforming structures, we will evaluate improvements to improve their performance.

Deliverable:

All model input, output and a summary of modeling results will be presented in tables, graphs and maps, along with priority location rankings according to City criteria and preliminary costs for replacement.

Proposed Budget

Completion of the above 4 tasks (entire project) will cost $107,531.10 (fixed fee). This fee includes $16,885.00 for a personal single-user license of MIKE SHE / MIKE 11 for the CoF and there will be no CD&E markup of that major capital expense. The cost breakdown by tasks is as follows:

Task 1: $32,016.65 (inclusive of software from DHI)

Task 2: $41,346.65

Task 3: $18,793.15

Task 4: $15,374.65

Total: $107,531.10

Please see the attached quote from DHI for the MIKE SHE / MIKE 11 software license.

Proposed Schedule

Please see the following schedule, which is premised on an August 1, 2015, start date.

Task #	Task	Activity	Aug					Sept				Oct				Nov				
			8/3	8/10	8/17	8/24	8/31	9/7	9/14	9/21	9/28	10/5	10/12	10/19	10/26	11/2	11/9	11/16	11/23	11/30
		Project Duration																		
1	Data Review																			
	Data Template	Fill out																		
	Additional Data	Gaps																		
2	Model	Develop																		
	Development	Calibrate																		
	Training	Training																		
		Presentation																		
3	Post-Fire Runs	Development and Runs																		
		Presentation																		
4	Infrastructure Runs	Development and Runs																		
		Presentation																		

Exhibit 1: Flagstaff Area Drainage Basins

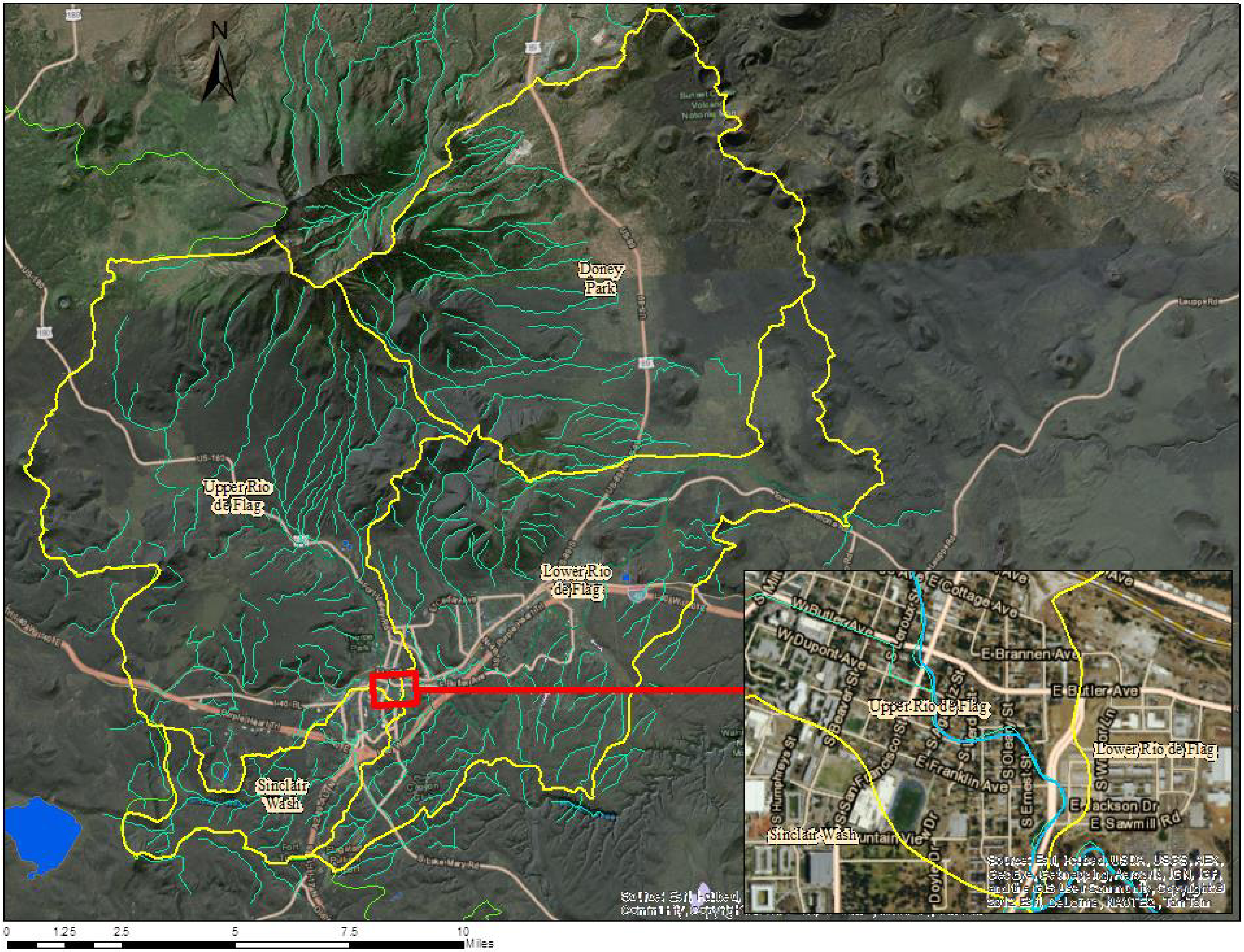

Exhibit 2: Extent of Local, High-Resolution Model

The scale bar is 0.5 mile long; the dots represent approximate locations where drainage infrastructure is probably undersized